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The analysis on sun tracking and cooling systems for photovoltaic panels

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ABSTRACT

This paper presents a review study on the effects of sun tracking and cooling systems. So far, many studies (and case studies too) have been analyzed and evaluated in the literature. Existing studies show that sun tracking system is significantly affecting energy generation capacity of photovoltaic panel. Other effecting parameter is the cooling system which has small effect on PV panel power generation but this totally depends on the location of installation system.

Contents

1. Introduction

Energy is one of the essential terminologies for the socio-economic development of developing, as well as developed countries. The growth of world population coupled with rising material needs has escalated the rate of energy usage [1,2]. This development causes to 4–8% increase of energy demand [3,4]. It is well known that energy, which is one of the main agenda of our world, is crucially important for the humanity. Many countries frequently tackle the problem of energy in order to balance the energy demand and supply. Therefore, extensive research should be attempted to present a more efficient way to use the energy and renewable energy resources effectively [5]. Therefore, the usage of energy is of great importance [5,6].

Today, large parts of energy generation sources are fossil fuels. So that the primary energy resources on the earth include fossil fuels. These sources are unfortunately not renewable and our environment is adversely affected by fossil fuels. The environmental issue has been rising in the worldwide scale such as global warming by exhausting carbon dioxide. The global environmental problem is a serious issue. In most countries, the economic activity that emits the largest amount of CO_2 is electric power generation plants. Meanwhile, burning of conventional energy sources emits lot of greenhouse gases, particularly CO_2. This process has very important effects on the climate change. Global warming and climate change poses an unprecedented threat to all human beings. Also, there are many studies in literature on negative effects of fossil fuels for our environment [3,4,7–16].

Omer [9] mentioned that achieving solutions to environmental problems that we face today require long-term potential actions for sustainable development. Enteria and Mizutani [10] support this idea as the technological innovation for future sustainable energy is necessary. Tampakis et al. [12] noted in their study that

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the development of renewable energy sources has been shown to follow an upward trend. Also, Hashim and Ho [13] outlined that initiatives on sustainable development are currently aggressively pursued throughout the world. In addition, Yuksel [14] supported that delivering sustainability demands that this access and security of supply should be provided, while avoiding environmental impacts, which would compromise future social and economic development. Akpinar et al. [15] noted that clean, domestic and renewable energy is commonly accepted as the key for future life. Dincer [5] outlined that renewable energy is a sustainable and clean source of energy derived from nature. Moreover, Dincer [17] noted that alternative energy plays an elementary function in resolving environmental pollution and warming problems at another study. Furthermore, Chen et al. [18] supported that renewable energy technology is one of the best solutions, which generates energy by transforming natural phenomena into useful energy forms.

Solar energy sources are the most dominant and abundant sources among the renewable energy resources [17]. Also, this source is nature friendly. It can be benefited from solar energy in two different ways such as thermal and electrical, as it is well known. Kuperman et al. [19] wrote that photovoltaic (PV) technology is one of the best ways to harvest the solar energy, since PV panels are strong and simple in design, require very little maintenance, and capable of giving outputs from microwatts to megawatts. There is a common consensus for solar energy which is the best way to generate electricity according to the many studies [1–19]. As known, solar energy has lots of advantages such as environment friendly, cost effective, clean, free, and non-depleting source. So that, nowadays, the solar energy power plants are increasing rapidly in the world.

PV panels convert solar radiation directly into electricity. This process does not increase carbon dioxide emissions production and does not harm the environment. Thus, PV power systems have received considerable attention for the clean energy resources to solve the environmental problem in the worldwide scale [5,20]. With understanding importance of carbon-free energy production, PV technology has received keen attention as a potentially widespread approach to sustainable energy production [21]. PV electricity energy system is much more effective, clean, and ergonomic source according to the other fossil energy sources. Therefore, many researchers and experts have been working on photovoltaic systems for many years. PV technology is rapidly improving day by day. This development provides to decrease PV panels costs. Currently, PV panels′ costs are feasible for investment.

There are some applications such as sun tracking, cooling systems, etc. to increase capacity of electricity energy generation. These applications also decreased investment costs.

One of the most important things in these systems is the sun tracking systems which must follow the sun during the day as a certain degree of accuracy since the sun is continuously moving. Other one is the cooling systems integrated PV panel that provides cooling of PV panel. As known, the heat of the PV panel increases during electricity energy generation. This situation causes to decrease the energy generation capacity of PV panel.

In this paper, a general review is presented on the sun tracking and cooling systems. Many researchers studied on these main factors. So, these factors have affected the energy generation capacity of the PV panels which are analyzed and evaluated in the present study. The paper is structured in three sections. Apart from the introduction part, Section 2 presents a brief literature review and description for sun tracking systems. Section 3 provides a description of the cooling systems and developed systems existing in literature. Section 4, presents the conclusion, which summarizes the main points that have been drawn up in this paper.

2. Sun tracking systems

Sun tracking systems monitor the sun during the day as the sun is continuously moving. It is well known that the electricity generation capacity of a PV panel depends on exposure to solar radiation in which the sun tracking systems provide this matter.

Many scientists have studied the sun tracking systems in different ways and applications to improve the efficiency of solar systems. A tracking mechanism must be reliable and able to follow the sun [22]. Fig. 1 shows operational states as fixed, tilted one- and two-axis tracking systems.

PV panels track the solar radiation via an automated one- or two-axis tracking system. These can be broadly classified as single-axis tracking, two axis tracking, and bi-annual tracking. Single axis trackers have one degree of independence that move as an axis of rotation. These trackers track the sun on a daily basis from east to west or north to south. Two-axis trackers have two degrees of independence that move as axes of rotation. These trackers track the sun both from east to west on a daily basis and from north to south on an annual basis [24,25].

Mousazadeh et al. [26] noted that one-axis tracking mechanism with PV power generation will increase by 24.5% as compared to that of a fixed PV module. Abdallah [27] outlined that there were an increase in the electrical power gain up to 43.87%, 37.53%, 34.43%, and 15.69% for the two axes, east–west, vertical and north–south tracking, respectively, as compared with the fixed surface inclined 32° to the south in Amman, Jordan. Abu-Khader et al. [28] found that there was an overall increase about 30–45% in the output power for the north–south axes-tracking system compared to the fixed PV system. Also, it was found that the north–south axes sun tracking is the optimum one. Al-Mohamad [29] found that the daily output power of the PV panel was increased by more than 20% in comparison with that of a fixed module. Abdallah and Nijmeh [30] noted that the two axes tracking surface showed a better performance with an increase in the collected energy of up to 41.34% compared with the

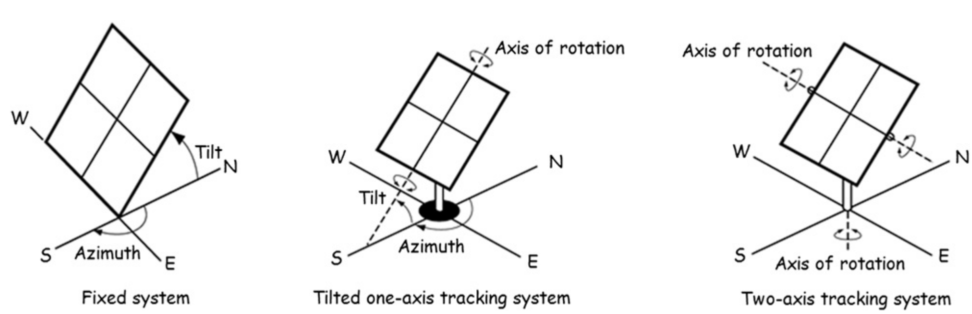


Fig. 1. Schematic representation of the fixed and tilted one- and two-axis sun tracking systems [23].

fixed surface. Mamlook et al. [31] outlined that the use of two-axis tracking would increase daily energy collection by more than 40%. Gómez-Gil et al. [32] wrote that the energy generation analysis shows: (1) compared with the fixed flat plate systems, one-axis and two-axis tracking flat plate systems have 22.3% and 25.2% gain in the annual energy generation analysis, respectively. Rustemli et al. [22] outlined that a comparison between fixed and sun tracked solar systems stills showed that the use of sun tracking increased productivity by around 29%. It can be concluded that the sun tracking system is more effective than the fixed system and capable of enhancing productivity. Kivrak et al. [33] wrote that the performance difference of a fixed tilt PV panel and a two-axis moving PV panel was compared for months of May and June and it was found that the energy generation increases nearly 64% for tracking system when it is compared with fixed PV system. Mousazadeh et al. [26] noted that it is not recommended to use tracking system for small solar panels because of high energy losses in the driving systems. It is found that the power consumption by tracking device is 2–3% of the increased energy. Furthermore, Abdallah [27] noted that the estimated consumed power by the electric motor and control system is less than 2% of the collected energy by the tracking system.

Many studies [22–33] showed that using a one- or two-axis sun tracking systems with PV panels significantly increase the total power output with respect to the fixed PV panels. These systems can be applied in all types of solar arrangements to increase their electricity generation capacity of PV panels. Lifetimes of sun tracking systems are approximately equal to PV panel lifetime. This time is about 25 years. Prices of these systems are changing between $0.4 and $ 1.6 per week [34].

This section also is discussed as an online sample of the sun tracking system with PV panel which has a great importance. Since, the obtained data with this sample gives an estimate for any selected area in European Countries. Besides, there are not any additional costs. This sample is designed by PV Geographical Information System (PVGIS). PVGIS incorporates a solar radiation database and gives climatological data of European as well as the other countries. PVGIS makes the simulation possible to calculate long-term average values and daily profiles of the irradiation on PV modules. PVGIS estimations have been widely used by developers to compare energy generation between fixed and tracking installations. Thus, we are also using it here to calculate the theoretical achievable energy generation for different PV configurations. [32].

This city Bitlis is selected to be used in the mentioned system where it is located in the east of Turkey as shown in Fig. 2. Firstly, geographical location is considered as a state of the system.

Secondly, required simulation data are obtained and evaluated as shown in Table 1, Figs. 3 and 4. Technical features of the sample are given as [35];

Performance of Grid-connected PV, PVGIS estimates of solar electricity generation:

Location: 38°23′37″ North, 42°7′23″ East, Elevation: 1488 m a.s.l.;

Solar radiation database used: PVGIS-classic;

Nominal power of the PV system: 1.0 kW (crystalline silicon);

Estimated losses due to temperature: 9.7% (using local ambient temperature);

Estimated loss due to angular reflectance effects: 2.9%;

Other losses (cables, inverter etc.): 14.0%;

Combined PV system losses: 24.5%;

Ed: Average daily electricity production from the given system (kWh);

Table 1
The geographic and system design values for indicated location and situation.

Month	Ed	Em	Hd	Hm
Fixed system, inclination = 35°, orientation = 0°				
January	2.30	71.3	2.85	88.4
February	2.88	80.6	3.55	99.4
March	4.12	128	5.29	164
April	4.17	125	5.41	162
May	4.56	141	6.12	190
June	4.63	139	6.34	190
July	4.54	141	6.33	196
August	4.38	136	6.10	189
September	4.55	136	6.22	187
October	3.87	120	5.16	160
November	2.77	83.2	3.62	109
December	2.21	68.6	2.79	86.6
Year	3.75	114	4.99	152
Total for year		1370		1820
2-axis tracking system				
January	2.54	78.8	3.22	99.8
February	3.21	89.9	4.02	113
March	4.94	153	6.46	200
April	5.17	155	6.72	202
May	6.06	188	8.14	252
June	6.36	191	8.69	261
July	6.15	191	8.54	265
August	5.61	174	7.79	241
September	5.81	174	7.96	239
October	4.53	140	6.15	191
November	3.10	93.1	4.15	124
December	2.45	75.9	3.16	98
Year	4.67	142	6.26	190
Total for year		1700		2290

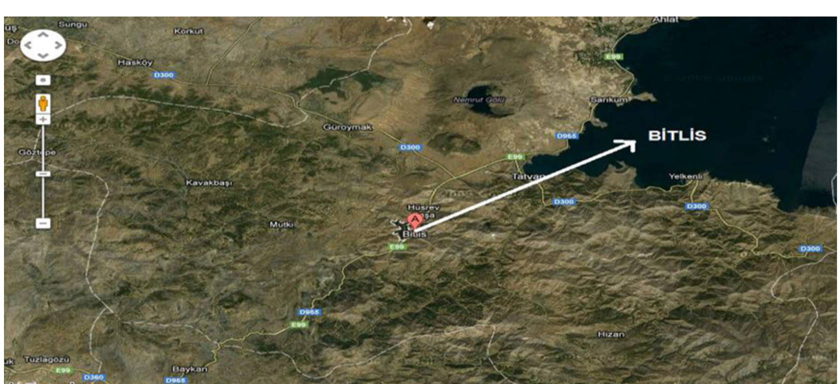


Fig. 2. Location of the selected city Bitlis by Google Earth.

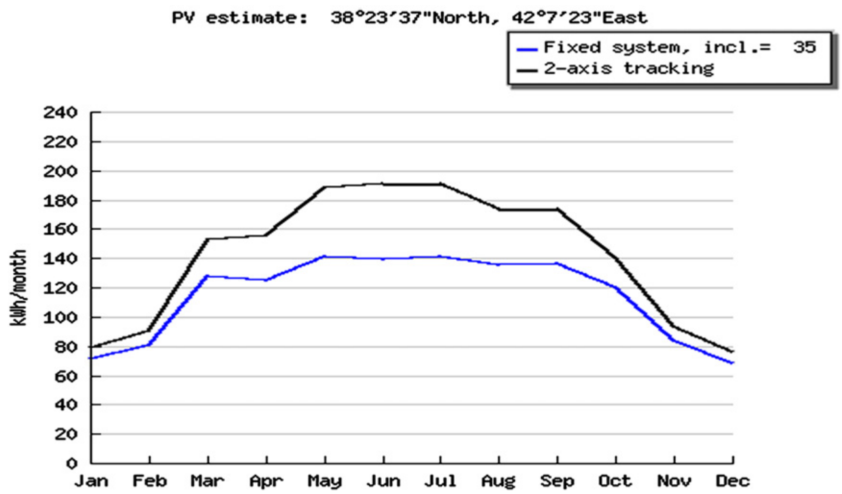


Fig. 3. Monthly energy output from fixed-angle PV system.

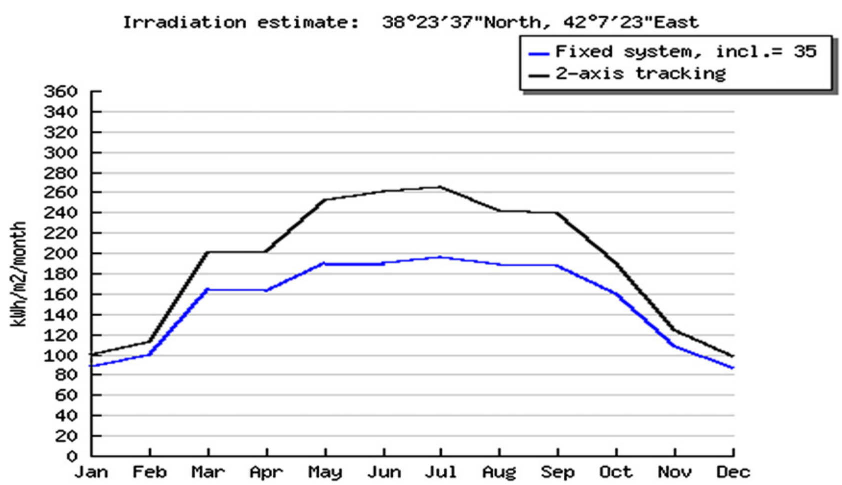


Fig. 4. Monthly in-plane irradiation for fixed angle.

Em: Average monthly electricity production from the given system (kWh);

Hd: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2);

Hm: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2).

The system is taking into consideration the values given in Table 1. Geographic values, PV panels and system are then evaluated. Electrical energy generation capacity of the system is also indicated. The diagrams are created by months. In addition, fixed system and two-axis tracking system with PV panels were also added to diagrams as shown is Figs. 3 and 4.

As mentioned before, the obtained data are for the city Bitlis. Fig. 3 shows that monthly energy output from fixed-angle PV system as kWh/month. As shown in Fig. 3, this city Bitlis has significantly solar energy potential. Especially, there is approximately power of 200 kWh solar energy potential for month of June and July with two axis tracking system. Also, Fig. 4 shows that monthly in-plane irradiation for fixed angle as kWh/m^2/month. Especially, there is approximately power of 270 kWh/m^2/month solar energy potential for month of June and July with two axis tracking system. This potential is very good and one of the best solar energy potential in EU (European Countries). These data depend on geographic location. In addition, these results show that two axis sun tracking systems have a great importance for electricity generation capacity of PV panels.

3. Cooling systems with integrated photovoltaic panel

It is well known that solar PV power generation is becoming widespread as a clean energy source for the earth. Though, the performance of PV panel is mainly evaluated under the standard test conditions (STC: 100 mW=cm^2 irradiation, 25 °C module temperature, and AM1.5 global spectrum). As known, the environmental factors affect the operation of the PV panels. These can be given as solar radiation, cloud and module temperature. Especially, among these, the module temperature seriously influences the generating performance of the PV panels [36–49].

Temperature effects are the result of an unnatural characteristic of crystalline silicon cell-based modules. They tend to generate higher voltage as the temperature drops and, conversely, to lose voltage in high temperatures. Any PV module or system calculation must include the adjustment for the temperature effect. The influences of temperature and irradiance on the cell characteristics are shown in Fig. 5. It is seen that the open circuit voltage increases logarithmically by increasing the solar radiation, whereas the short circuit current increases linearly [50–52].

In addition, there are many studies in literature on the negative effects of operating temperature for PV panel. Many scientists have studied the negative effects of increasing operation temperature to improve the efficiency of PV panels since the increasing operation temperature negatively affect to PV panel. This change is totally dependent on the module types. Skoplaki

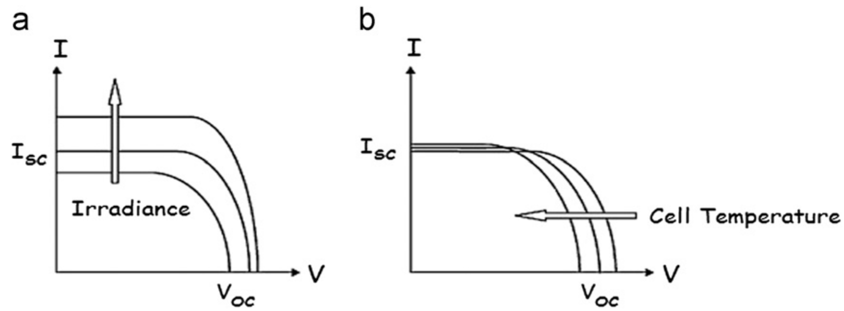


Fig. 5. Effects of solar radiation (a) and cell temperature (b) on PV electrical characteristic [52].

and Palyvos [39] noted that a key variable for the PV conversion process is the operating temperature of the cell/module. Rustemli and Dincer [49] outlined that increasing of panel temperature is affected electricity generation capacity of PV panels and as the panel temperature is increasing, current is very little increased but voltage is decreased. Bloem [40] supported that idea as the measurement of the electrical performance of PV elements has already been standardized to a large extent. The electrical efficiency, however, is dependent on the temperature of the PV element. Tiwari and Sodha [41] outlined that one of the main reasons for reduction of electrical efficiency of the PV module is the increase in the temperature of the PV module due to solar radiation. Another study by Tiwari and Sodha [42] wrote that in order to increase the efficiency of the PV module, the temperature of the PV module should be decreased. Sandnes and Rekstad [43] noted that PV cells in a hybrid energy-generating unit that simultaneously produced low temperature heat and electricity. Trinuruk et al. [44] noted that the temperature of PV cells is one of the most important parameters for assessing the long term performance of PV module systems and their annual amounts of electrical energy production. Ye et al. [45] wrote that the efficiency of PV (PV) modules is strongly affected by their operating temperature. Typically for every 1 °C increase of module temperature, there is a ~0.45% drop of module efficiency for crystalline silicon modules. For thin-film modules, this efficiency loss is only about half of that of crystalline silicon technology. Skoplaki and Palyvos [46] noted that the operating temperature plays a central role in the PV conversion process. Butay and Miller [48] supported that idea as a PV module′s temperature has a great effect on its performance. Also, in general, a crystalline silicon PV module's efficiency will be reduced about 0.5% for every °C increase in temperature. Mattei et al. [47] noted that most of the solar radiation absorbed by a PV panel is not converted to electricity but contributes to increase the temperature of the module, thus reducing the electrical efficiency.

The main effect of the increase in cell temperature is on open circuit voltage, which decreases linearly with the cell temperature; thus the cell efficiency drops. Also, the short circuit current increases slightly with the increase of the cell temperature [52]. The heat generated yields to an increase in cell temperature and consequently to a decrease in conversion efficiency of electricity. So, that the temperature has a negative effect on the panel performance [53].

The conversion efficiency decreased with a rise of the module temperature. The temperature coefficient of heteromodule, c-Si module and p-Si module was −0.3%/°C, −0.4%/°C and −0.4%/°C respectively. This indicates that the system is strongly affected by the temperature coefficient of the conversion efficiency when the module temperature becomes high [36].

Consequently, many studies show that the efficiency of the PV panel decreases as operating temperature increases. There are some cooling methods [39–49] to increase efficiency of the PV panel such as water cooling, water tank, PV/Thermal etc. Therefore, Odeh and Behnia [38] studied the water cooling system due to increase PV panel temperature as experimental. They proposed a water cooling technique using water from the storage tank. They had achieved to increase power of about 15% according to the current state. Another advantage of using water for cooling the upper surface of the PV module is the increase in surface input radiation due to the refraction in water layer. Also, Butay and Miller [48] noted that the cooling system on a PV panel will have its power reduced by approximately 12.5%. These studies are phase of experimental. However, these systems are not cost effective as seen according to the experimental studies.

4. Conclusion

Solar energy is the most abundant and dominant source among the renewable energy resources. Electricity generation from solar energy does not contribute the carbon dioxide emissions and production. This energy source does not harmful for the environment. It is nature friendly. Also, solar energy source is one of the fastest growing sources of renewable energy sources. Especially, the installed capacity of solar power has increased in recent years.

Many studies [22–33] showed that using sun tracking systems significantly increase electricity energy generation capacity of PV panels. Gain rates of these systems depend on the location and area of the PV panels. Generally, this rate is approximately between 15%–45% throughout the year. With two-axis sun tracking systems are more approximately 10%–20% generated electricity energy generation than one-axis sun tracking systems. Therefore, sun trackers should use with PV panels.

Furthermore, most studies showed that the conversion efficiency decreased with a rise of the module temperature. This decreasing conversion efficiency depends on PV panel types. To decrease PV panel temperature can be applied lots of methods such as water cooling, water tank, PV/Thermal etc. Unfortunately, these systems are having no effective cost. This situation depends on location and area of PV panels too. If the PV panels′ installation location is seaboard, this system can be used more effectively.

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